Fermi National Accelerator Laboratory

Technical Division

Magnet Test Facility

Automated Isolation Amplifier Calibrator

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<u>Abstract</u>

The technical work accomplished during the summer internship at the Fermi National Accelerator Collider consists of the calibration of in-house constructed programmable isolation amplifier modules using the AD210 3-Port Isolation Amplifier from Analog Devices. The calibration of numerous isolation amplifier modules was done using the same method that has been used for about six years.   An automated calibrator for the isolation amplifiers was also created using the LabView software programming language by National Instruments. The final system includes the Fluke 5440B power supply, the Hewlett Packard 3458A multimeter, the Keithley 7001 Switch System, the Motorola MVME1600-001 VME processor, and a custom-made LabView Graphical User Interface (GUI).

Background

The Fermi National Accelerator Laboratory is a proton and antiproton accelerator and collider laboratory that studies high-energy physics and the nature of matter. Fermilab is home of the Tevatron, which is the world's largest working accelerator and collider. The Tevatron is a four-mile-long underground ring that consists of two detectors, a main injector, a proton source, and an antiproton source. Figure 1 illustrates the overall view of the proton – antiproton collider.
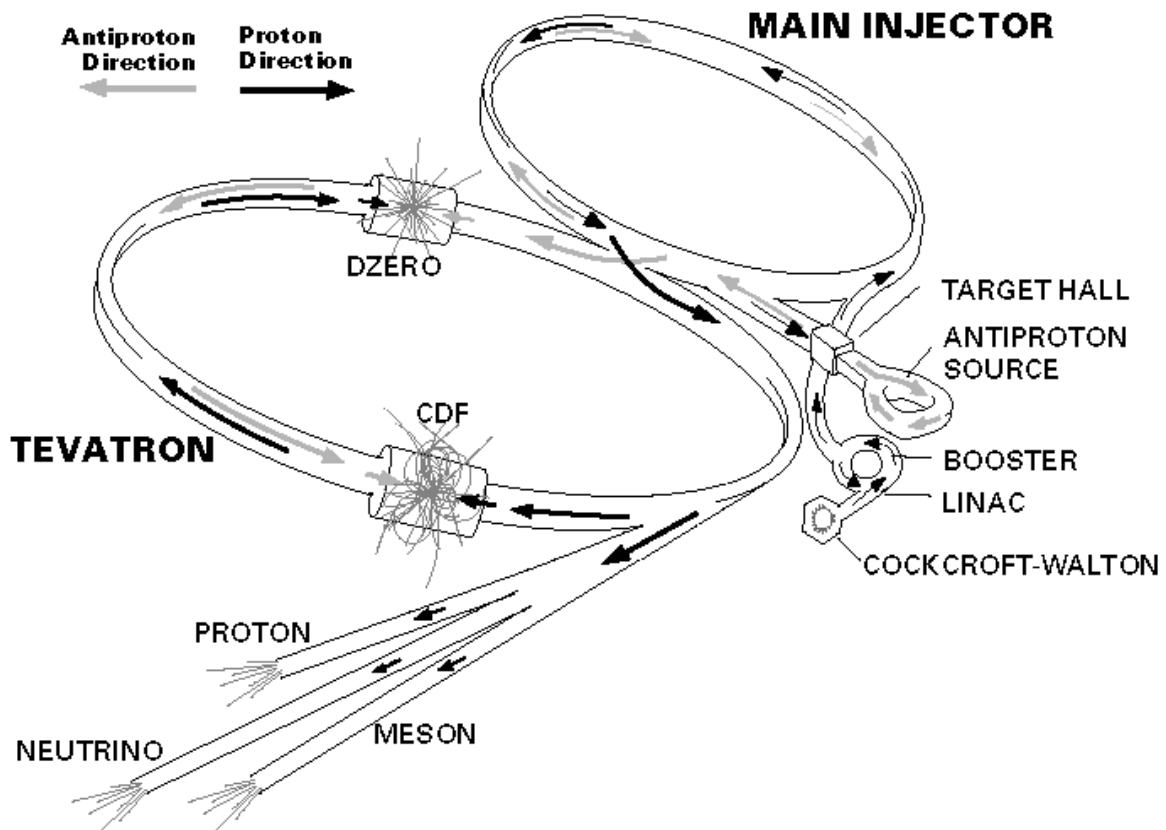

Figure 1: Tevatron Overview [1]

The source of the collider is the Cockcroft-Walton accelerator, which accelerates H⁻ ions to 750,000 eV (electron volts), where $1 \text{ eV} = 1.602 \text{ X } 10^{-19}$ J.[1] The ions then

pass through the Linear Accelerator (LINAC) and are accelerator to 400 MeV. The ions

are then passed into the Booster, where the electrons are stripped off and the protons are

accelerated to 8 MeV.[1] The protons are transferred to the Main Injector, where the

antiprotons are created by colliding the protons to a fixed target in the target hall. The

antiprotons are separated from the protons and sent the opposite direction as the protons

around the main ring. The proton and antiproton beams are accelerated to 150 GeV and

sent into the Tevaron, where the beams are accelerated to 1TeV.[1]   The protons and

antiprotons are collided in the CDF and DZERO experiments where data of the collisions

is taken.

Superconducting magnets in the Tevatron are used to bend the proton beam and

antiproton beam in the ring and to focus the beams. Figure 2 contains the front view of a

new quadrupole magnet made in Fermilab for CERN in Geneva, Switzerland.
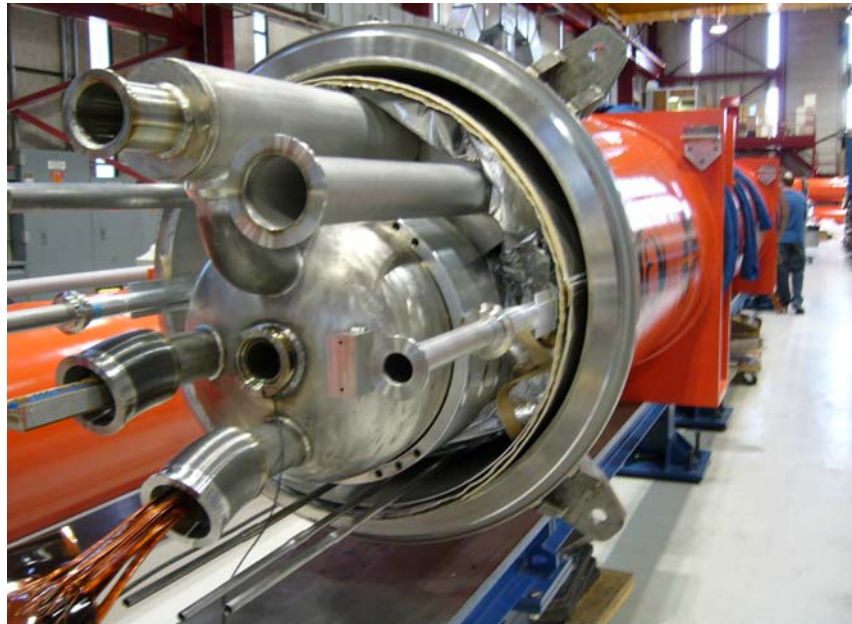

Figure 2: Quadrupole Magnet [1]

As high values of current, usually more than 10 kA, pass through the magnets, they begin to quench, or increase in resistance and temperature. Quenching of superconducting magnets damages the magnets and causes them to malfunction.

The Technical Division at Fermilab designs and produces many in-house instruments and devices to accomplish tasks for the construction and testing of superconducting magnets used in the Tevatron. The Magnet Test Facility has created a Test Stand Area Quench Management System Module to provide quench detection and protection for the superconducting magnets. Among other things, this system monitors/controls the magnet protection hardware and monitors the magnet under test for the onslaught of resistive voltages.[2] This system contains four test stands using VersaModular Eurocard (VME) crates to hold and control the hardware used. The VME crates include a series of 8-channel programmable isolation amplifier VME cards that isolate the detection and protection hardware from the magnets. The block diagram in Figure 3 shows the role of the isolation amplifiers in the testing of the magnets.
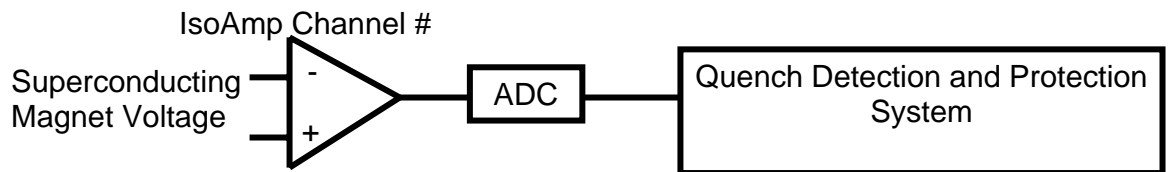
Figure 3: Isolation Amplifier Setup

Accuracy of the isolation amplifiers is vital for the quench detection system to be able to detect the quenching of the magnet. The isolation amplifiers are in-house designed and built and each channel contains an AD210 3-Port Isolation Amplifier by

Analog Devices. A front and side view of an isolation amplifier card is shown in Figure 4.
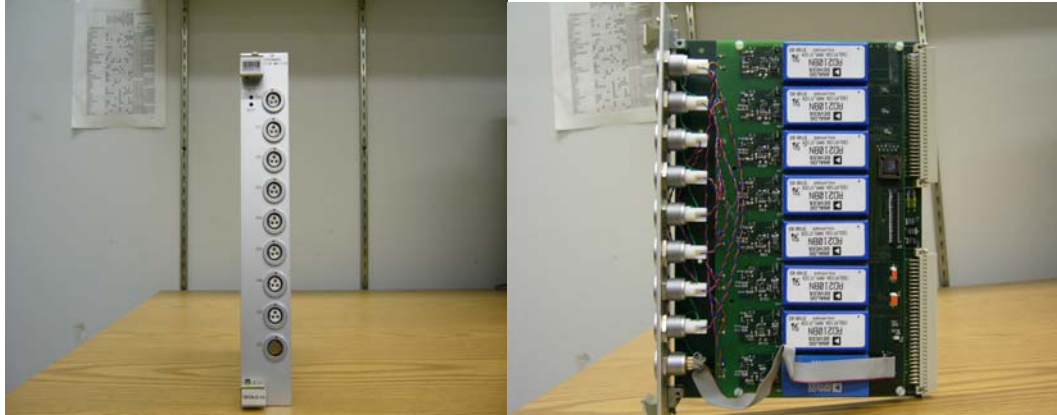

Figure 4: Programmable Isolation Amplifier Card

The isolation amplifiers are connected across different sections of the superconducting magnet under test to output analog voltages to analog-to-digital converters and other VME devices in the VME crate used to collect real-time data of the magnets. For accuracy of the system, the programmable isolation amplifiers are calibrated yearly.

Objectives

The technical responsibilities assigned for the summer internship were (1) to calibrate the programmable isolation amplifiers using the earlier method of calibration and (2) to create a more convenient automated calibrator to reduce time and work for the calibration procedure.

The earlier method of calibration uses HyperTerminal to communicate via serial port with a MVME1600-001 VME processor. A VxWorks program named ia8.c has been previously written and can be loaded onto the VME processor from a local server to write

gains to and read previously written gains of the isolation amplifiers. A snapshot of the

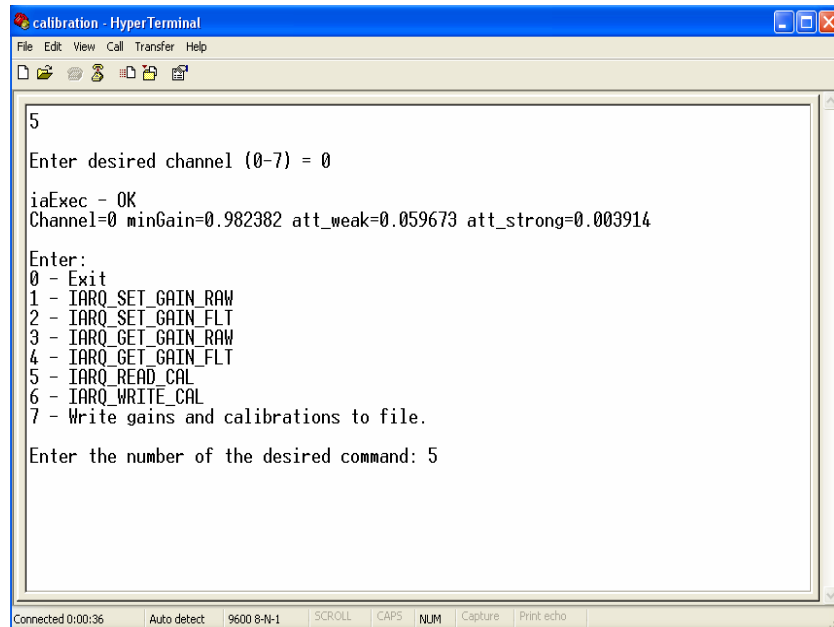commands available in the program is shown in Figure 5.

Figure 5: ia8 Options

As can be seen in the figure above, Option 0 exits the program. Option 1 sets a

predefined gain depending on which option the user specifies: attenuation 1, attenuation

2, or attenuation 3. Options 3 and 4 read prewritten gain values that are set in the

amplifier. Option 6 is used to write the following calculated values to the amplifier:

minGain, att_weak, and att_strong. Option 5 will allow the reader to view the last values

that were written to the amplifier from Option 6.

A power supply and multimeter are manually controlled during the calibration

procedure and an excel spreadsheet containing the output values is completed for each

isolation amplifier card. The spreadsheet contains pre-calibration readings and post-

calibration readings of each channel in the module. The excel spreadsheet also calculates

the values of minGain, att_weak, and att_strong, which are needed to calibrate the

isolation amplifiers using the attenuation codes 1, 2, and 3. In the beginning of the

project, every isolation amplifier was calibrated using the earlier method.

The main goal for the project was to create an automated system that calibrates

the programmable isolation amplifiers. The new calibration system uses LabView to

control the power supply, multimeter, and switch system via General Purpose Interface

Bus (GPIB), as requested by the supervisor. The program also reads feedback from and

sends commands to the MVME1600-001 VME processor via serial port COM1. The

LabView program also creates a table for the user to view during the calibration

procedure where the values for minGain, att_weak, and att_strong are calculated. The

program stores the data in the table into an excel spreadsheet specified by the user. The

excel spreadsheet is completed in the same form as in the earlier method of calibration.

The new system eliminates manual control of the instruments used by the person

calibrating the isolation amplifiers and uses the VxWorks program, ia8.c, to communicate

with the isolation amplifiers. It also reduces time for the calibration procedure and

consists of the same accuracy as the current method of calibration.

Automated Calibration System

The technical approach taken to accomplish these tasks first consists of

calibrating all isolation amplifiers using the ia8 program and HyperTerminal. The

manual control of the equipment was required as well as the manual entry of data into the

excel spreadsheet. A calibration procedure document was followed to complete the

calibration of the isolation amplifiers. This ensured that each isolation amplifier module

that was calibrated was ready to be used in the Magnet Test Facility and verified those
that could no longer be used due to malfunction.

Since the VxWorks program, ia8, is used in the new system, the mathematical
concept to calibrate the AD210 isolation amplifier remains as before.

Hardware Setup

The hardware for the new system includes the Fluke 5440B power supply, the
Hewlett Packard 3458A multimeter, the Keithley 7001 Switch System, and the
programmable isolation amplifier modules, all of which are placed in the calibration
crate. The block diagram in Figure 6 illustrates the hardware setup of the calibration
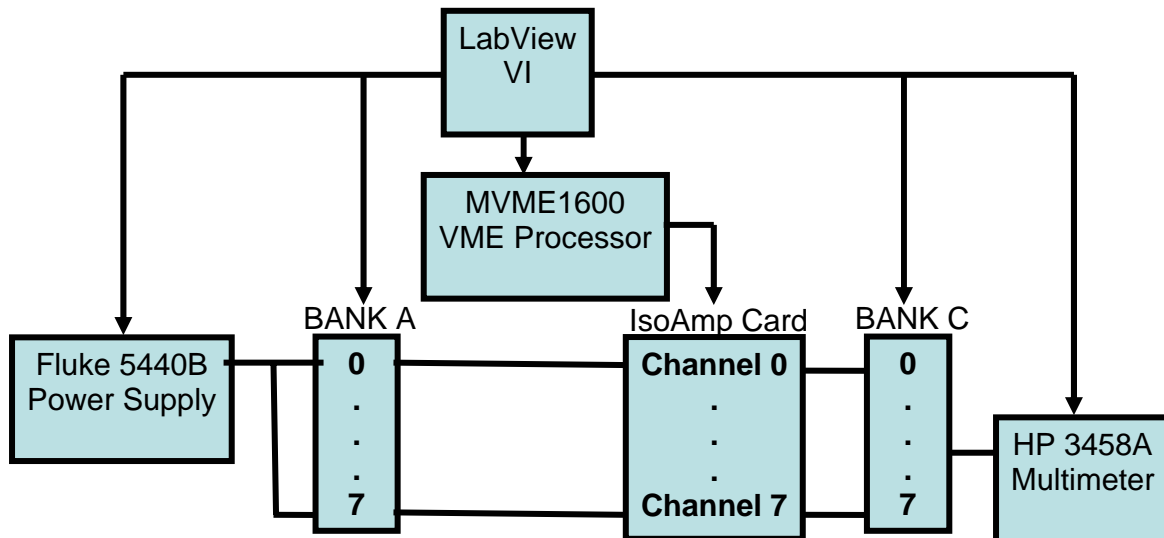system.

Figure 6: Hardware Block Diagram

Three GPIB cables are daisy chained together to connect the power supply,
multimeter, and switch system to a GPIB card in the computer running the LabView
program. Bank A and C in the block diagram above are rows of FET switches in the

switch card inserted in the Keithley 7001. The output of the power supply is connected to one side of switches 0 through 7 in Bank A. The other side of each switch in Bank A is connected to an individual, separate channel input of the isolation amplifier VME card. The output of each channel in the isolation amplifier card is connected to one side of its corresponding switch in Bank C. All switches in Bank C are connected to the input of the multimeter used in the system. With this setup, individual channel selection can be made. For instance, to read the output of only the first channel of the isolation amplifier card, Switch 0 in Bank A and Switch 0 in Bank C are switched on. This allows a connection between the power supply to the input of the channel and a connection between the output of the channel and the input of the multimeter. All other channels of the isolation amplifier card are unused as long as their corresponding switches in Bank A and C remain switched off.

As seen in Figure 6, the LabView program also controls the Motorola MVME 1600 VME processor. This is done via serial connection between COM1 of the computer and the VME processor. Communication between the VME processor and the isolation amplifier card is done via VMEbus.

Software

The software overview of the final LabView program can be broken down into three parts. The first part of the program consists of the initialization of the VME processor and the isolation amplifier card. The second part consists of calibrating each channel of the isolation amplifier card by setting parameters to the hardware and scanning through each channel. The third part consists of writing the calculated gain

values (minGain, att_weak, and att_strong) to each channel of the isolation amplifier card

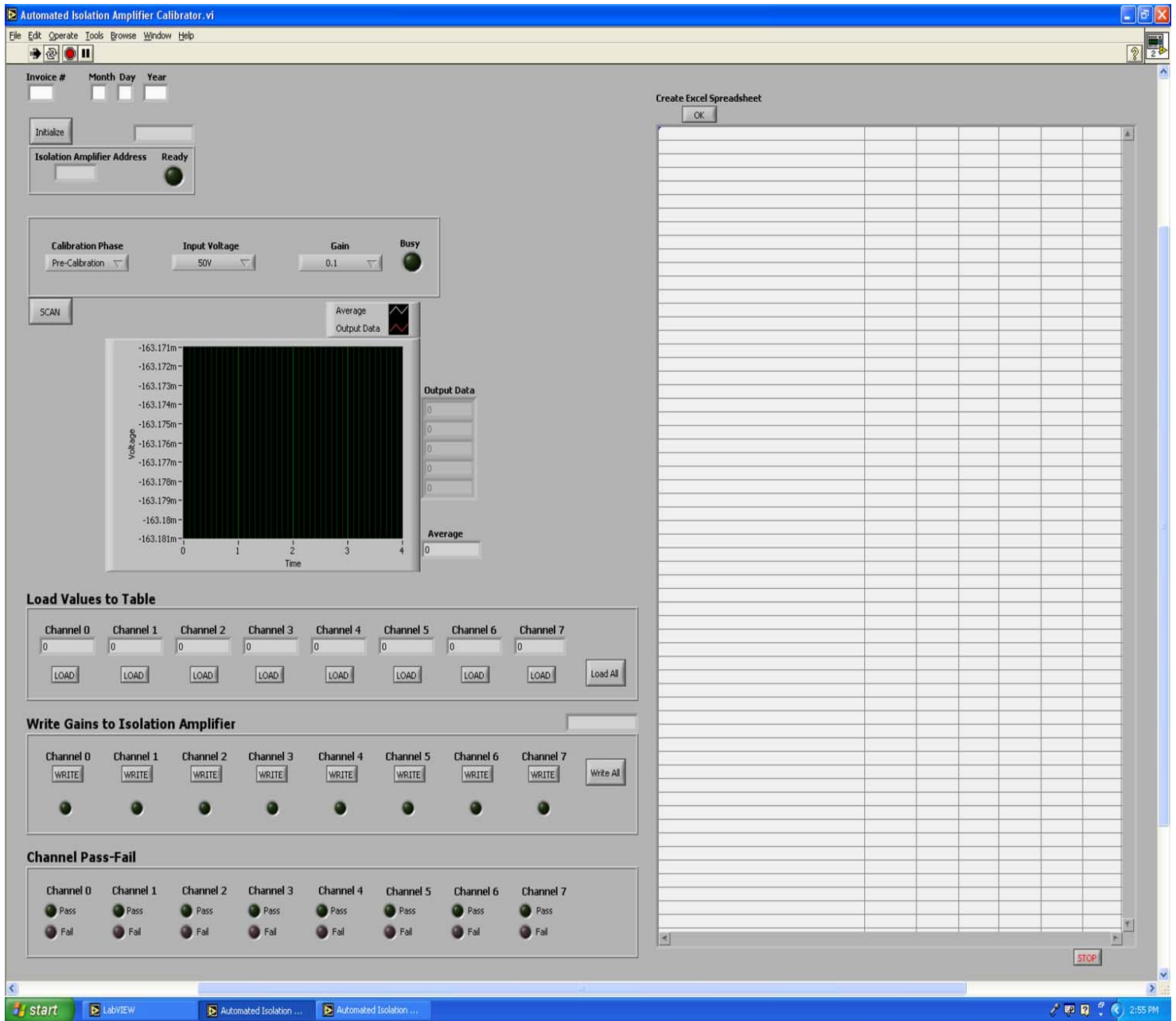for calibration. Figure 7 contains a screenshot of the LabView GUI before initialization.

Figure 7: Empty LabView GUI

Initialization

       The first input data required from the user is the invoice number of the isolation

amplifier card and the date of calibration. After the data is entered, the "Initialize" button

is pressed and the VME crate is powered on or reset. The flow chart in Figure 8 shows

the initialization process of the program.
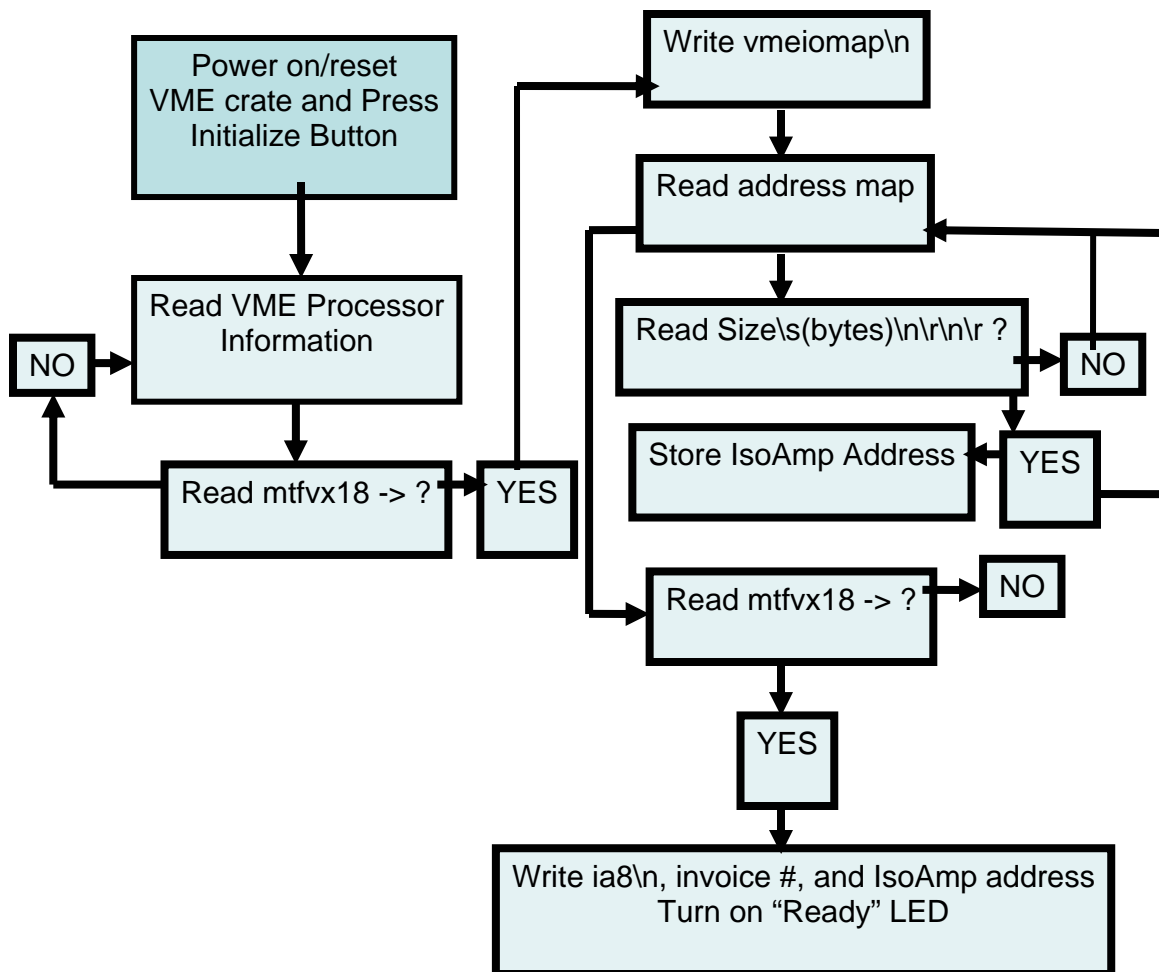
Figure 8: Initialization Flow Chart

       When the VME crate is turned on or reset and the "Initialize" button is pressed,

the LabView program begins reading the VME processor initialization information. This

information contains programs being loaded from the server and other information about

the VME processor itself. The program continually reads the string output of the VME

processor until the following string is sent from the VME processor: "mtfvx18 ->". This

string indicates that the VME controller is initialized. The program then sends the

following string to the VME processor: "vmeiomap\n". This commands the VME

controller to open the vmeiomap program in the server and send out the address of every

VME device plugged into the VME crate. The LabView program continuously reads the

address map and locates the address of the isolation amplifier card by taking the ten

string characters that follow the string: "Size\s(bytes)\n\r\n\r". The isolation amplifier

address is stored and the program continues reading the address map until "mtfvx18 ->"

is read. When the condition is met, the LabView program opens the ia8 program in the

VME processor. It then sends the invoice number and the stored address of the isolation

amplifier card to the VME processor to finish the initialization process. The "Ready"

LED is turned on to let the user know when the initialization process is complete.

Scanning Process

The second part of the program consists of allowing the user to set the input

voltage and gain parameters of the isolation amplifier and scanning through all of the

channels of the isolation amplifier card to read the output of each channel.

The LabView GUI contains three rings: Calibration Phase, Input Voltage, and

Gain. When a ring is selected, a drop-down menu appears and the user may select the

parameters of each. The Calibration Phase ring contains the following options: Pre-

Calibration, Attenuation 1, Attenuation 2, Attenuation 3, and Post-Calibration. The Pre-

Calibration process is run before the actual calibration of the isolation amplifier channels

is done. Attenuations 1, 2, and 3 are pre-defined attenuations that are used for the

calibration and make the values of the Gain ring irrelevant. The Post-Calibration process

is run after the calibration and is used to check for more accurate readings from the

isolation amplifier channels. The Input Voltage ring contains the following options: 50V,

5V, 0.5V, -0.5V, -5V, and -50V. The chosen option indicates the voltage the power

supply will be set to during the scanning process. The Gain ring contains the following

options: 0.1, 1, and 10. The chosen value will be written to the isolation amplifier

channels only during the Pre-Calibration and Post-Calibration phases.

The following flow chart in Figure 9 illustrates the scanning process taken

in the second part of the LabView program.
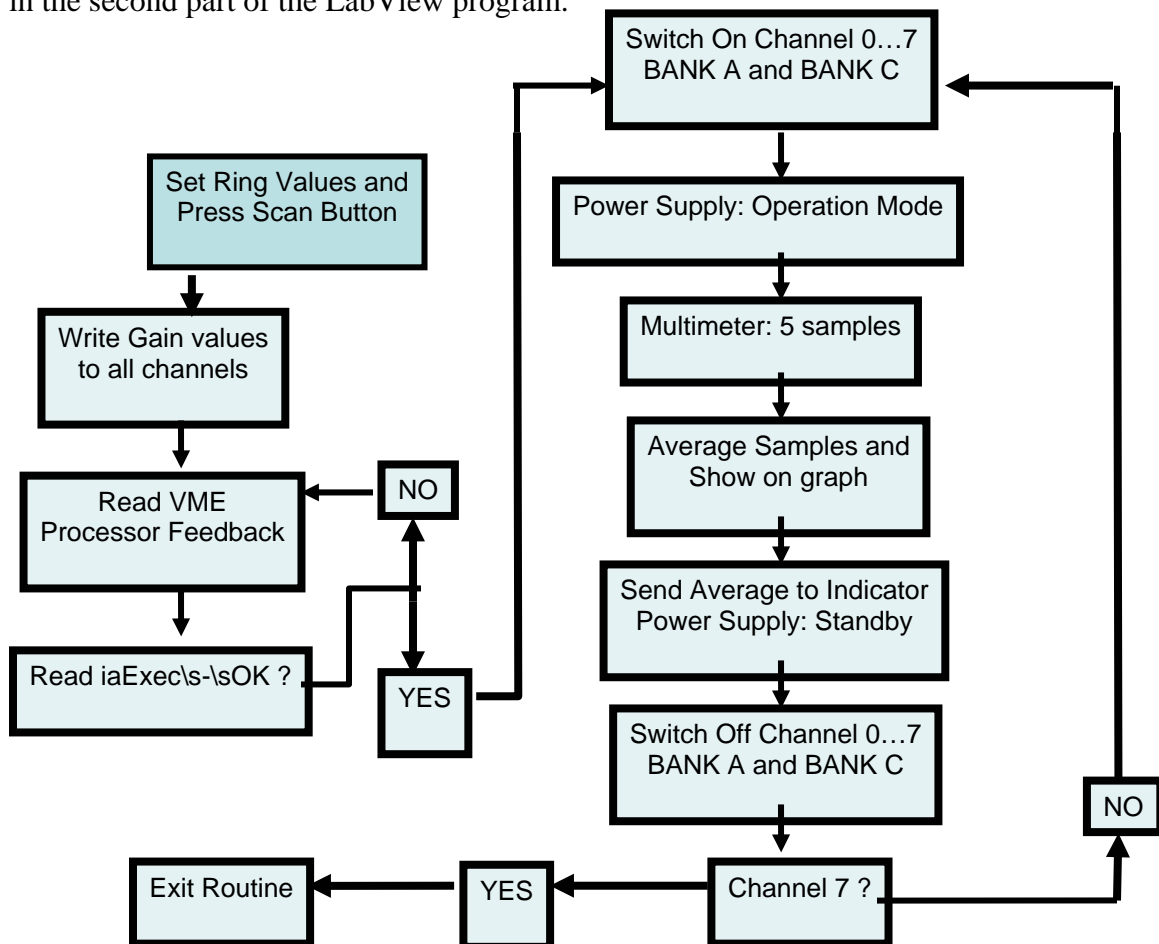
Figure 9: Scan Flowchart

After the ring values are set and the scan button is pressed, the chosen gain by the user is written to all channels of the isolation amplifier card. The program continuously reads the feedback sent from the VME processor and stops reading when the processor sends: "iaExec – OK". At this point, the scanning of the channels begins. First, Switch 0 in Bank A and C are switched on. The power supply is set to the voltage level specified by value of the Input Voltage ring and is set to Operation Mode. The voltage now the input voltage of Channel 0 of the isolation amplifier card and the output voltage is read by the multimeter. The multimeter takes five samples with a one-second time duration between each. The LabView program stores the five samples into an array and calculates the average value. The average and sample values are illustrated in a graph on the front panel of the GUI and the average value is sent to an indicator box for the corresponding channel. The process is then repeated for all other channels, sequentially.

After all channels are sampled, the user has the option to load the values onto the table shown in Figure 7.

Writing Gain Values

As Attenuation 1, 2, and 3 are being loaded onto the table during the scanning process, the LabView program is calculating the values for: minGain, att_weak, and att_strong. The equations for these gains are shown below.

$$\textbf{minGain = (Volt1 – Volt2)/10}$$

$$\textbf{att\_weak = (Volt3 – Volt4)/10/(Volt1 – Volt2)}$$

$$\textbf{att\_strong = (Volt5 – Volt6)/10/(Volt1 – Volt2)}$$

Calibration Phase	Input Voltage	Output Voltage
Attenuation 1	+5V	Volt1
Attenuation 1	-5V	Volt2
Attenuation 2	+50V	Volt3
Attenuation 2	-50V	Volt4
Attenuation 3	+50V	Volt5
Attenuation 3	-50V	Volt6

The table above shows the conditions needed for the Calibration Phase ring and the Input Voltage ring to get the necessary values to calculate minGain, att_weak, and att_strong.

After the Attenuation 1, 2, and 3 phases have been run, the gains are fully calculated. The LabView GUI has a "Write Gains to Isolation Amplifier" section where the user may write the gains to each channel. In this process, minGain, att_weak, and att_strong are written respectively to the channel specified by the user. An indicator LED under each "Write" button lights on when the corresponding channel has been calibrated.

An extra feature added to the program consists of the Channel Pass-Fail section. After the Pre-Calibration phase has been completed, the program checks to see if every value is within +/- 5% of the expected value. If the condition is met, the "Pass" LED lights on. If one or more of the values is out range, the "Fail" LED lights on. This feature lets the user know if there are any malfunctioning channels in the isolation amplifier card.

Results

Figure 10 below shows the LabView GUI after the calibration process is completed.
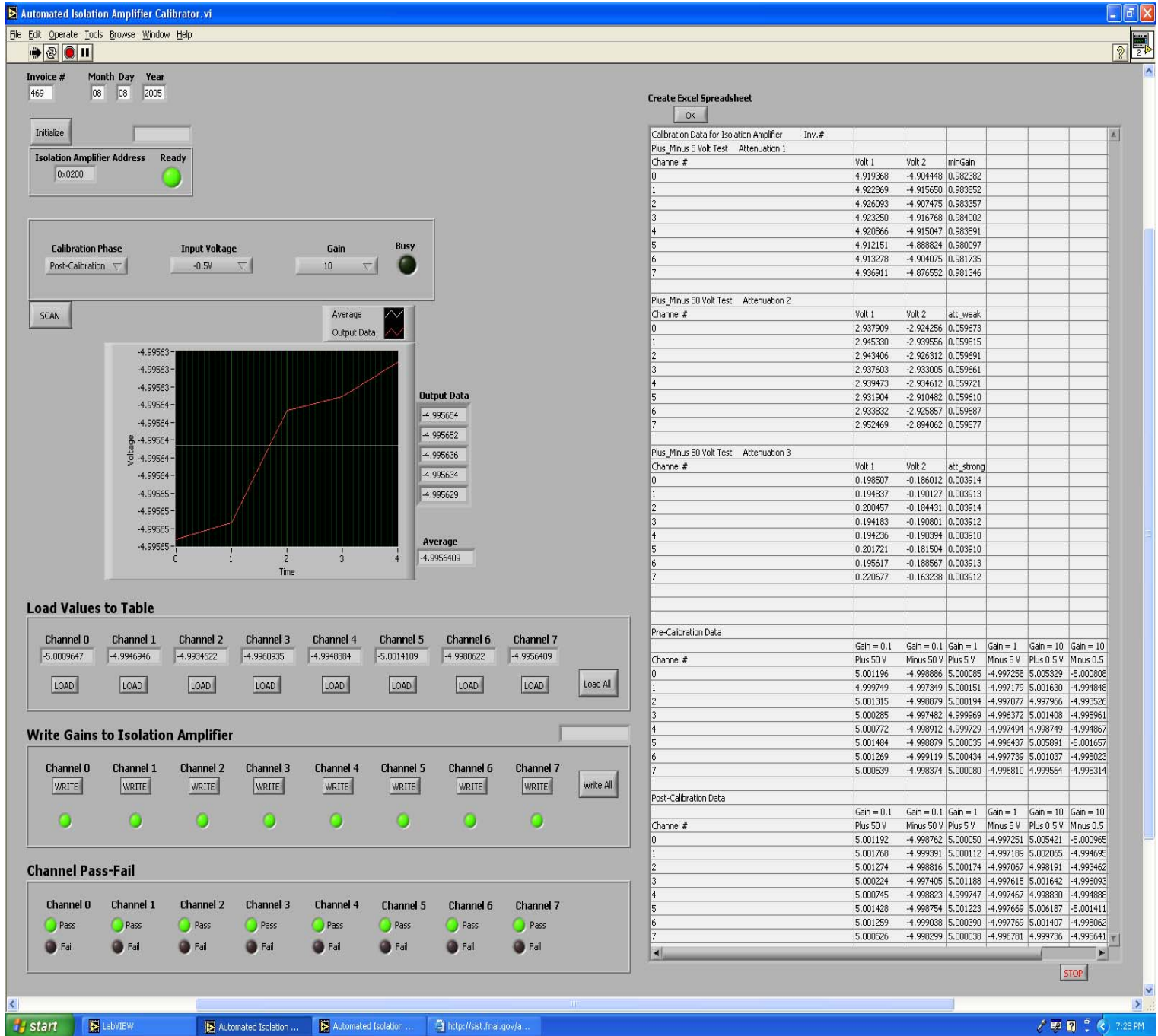
Figure 10: Full LabView GUI

As can be seen in Figure 10, all channels have been calibrated and all channels passed. The table shows the data gathered during the calibration process and the graph shows the values of the last run of the calibration procedure.

The user also has the option to send the table to a Microsoft Excel spreadsheet. When the "Create Excel Spreadsheet" button is pressed, the user is asked to enter the desired name of the spreadsheet file. The file is then created and the spreadsheet is in the same format is the table in the GUI. Figure 11 contains a screenshot of a spreadsheet file created by the LabView program.

Figure 11: Calibration Spreadsheet File

As a result of the final product, the calibration time has been reduced from about two hours to approximately twenty-five minutes. Accuracy has also been increased by reducing the possibility of error from the person performing the calibration.

References

1. www.fnal.gov

2. R. Carcagno, D.F. Orris, "A Modular and Extensible Data Acquisition and Control System for Testing Superconducting Magnets", *Particle Accelerator Conference*, 2001.

Acknowledgements